CHARM: A CUBESAT WATER VAPOR RADIOMETER FOR EARTH SCIENCE

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ABSTRACT

The Jet Propulsion Laboratory (JPL) and Ames Research Center (ARC) are partnering in the CubeSat Hydrometric Atmospheric Radiometer Mission (CHARM), a water vapor radiometer integrated on a 3U CubeSat platform, selected for implementation under NASA Hands-On Project Experience (HOPE-3). CHARM will measure 4 channels at 183 GHz water vapor line, subsets of measurements currently performed by larger and more costly spacecraft (e.g. ATMS, AMSU-B and SSMI/S). While flying a payload that supports SMD science objectives, CHARM provides a hands-on opportunity to develop technical, leadership, and project skills. CHARM will furthermore advance the technology readiness level (TRL) of the 183 GHz receiver subsystem from TRL 4 to TRL 6 and the CubeSat 183 GHz radiometer system from TRL 4 to TRL 7.

***Index Terms* —** *Microwave radiometry, Atmospheric measurements, Low earth orbit satellites, CubeSat, MMICs*

1. INTRODUCTION

The CubeSat Hydrometric Atmospheric Radiometer Mission (CHARM), proposes to combine a 183 GHz radiometer instrument developed at JPL with a CubeSat bus developed at ARC. JPL has demonstrated 183 GHz receiver performance with noise temperatures lower than ~438 K (4 dB noise figure) [1]. A 183 GHz radiometer is ideal for the CubeSat platform which has stringent mass, power and volume requirements. ARC would provide a custom CubeSat bus based on significant experience building and flying small spacecraft missions, having already flown 4 CubeSats.

In addition to advancing the TRL of the receiver and CubeSat systems, CHARM will also provide complementary measurements that can be utilized in current models and new algorithms, contributing to both Science Mission Directorate (SMD) technology and science goals, at a significantly reduced cost (presently \$3 million), while fulfilling the primary goal of NASA HOPE-3 to provide hands-on flight project experience to enhance technical, leadership, and project skills for the selected in-house project team.

2. 183 GHZ RADIOMETER

The enabling technology in this effort is the Northrop Grumman Corporation (NGC) indium phosphide (InP) 35 nm high electron mobility transistor (HEMT) process [2], which was initially developed under a Defense Advanced Research Projects Agency (DARPA) program aimed at applications above 300 GHz. The Earth Science Technology Office (ESTO) has made significant investment into the technology and related instruments, and applied specifically to 183 GHz at JPL has resulted in a reduction in power while improving noise performance [3].

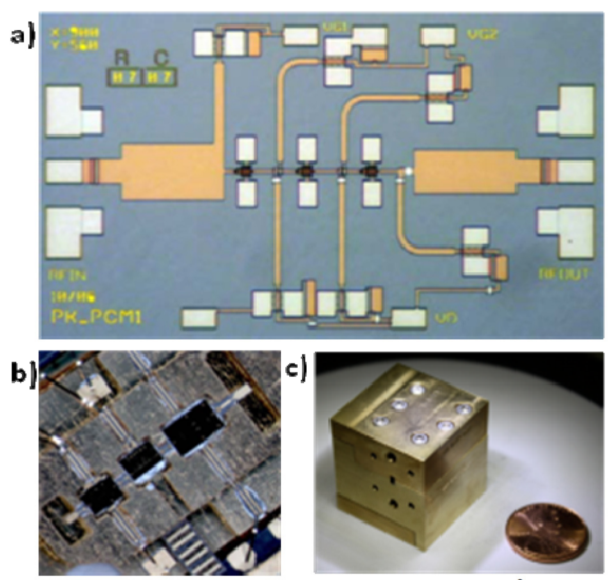

Figure 1. a) InP amplifier, 900x560 μm^2
b) 2 amplifiers and a subharmonic mixer in a package
c) Packaged receiver with a penny

Figure 1 shows the physical scale of the technology starting from the smallest building block at 900x560 μm^2 [3], to an intermediate stage with 2 amplifiers and a sub-harmonic mixer wire bonded [1], to a fully integrated receiver block

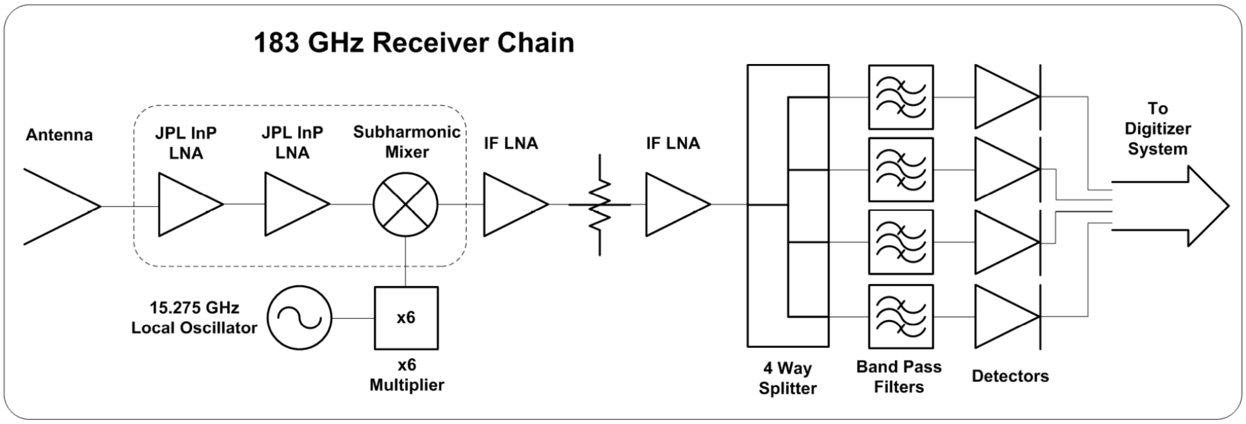

Figure 2. Proposed 183 GHz receiver chain with four channel output. The outlined parts represent the JPL developed frontend.

that was developed internally at JPL for cosmic microwave background measurements [4].

The proposed radiometer configuration is shown in Figure 2. Calibration of the radiometer will be performed by external cold space/Earth limb looks, and vicarious scene comparison combined with an extensive pre-launch testing campaign to determine the receiver characteristics over temperature. The dash-outlined block represents a custom JPL packaging that would house the InP low-noise amplifiers (LNAs) and sub-harmonic mixer, similar to that in Figure 1c. The intermediate frequency (IF) subsystem feeds a four way splitter with band definition filters. Nominally the radiometer will measure around 183.31 GHz at ±1, 3, 4.5 and 7 GHz (4 of the 5 ATMS 183 GHz channels).

Minimal development is required for the configuration shown in Figure 2 as the majority of components are available commercially off-the-shelf (COTS) except the antenna and JPL-developed receiver. The antenna will be based on the mature offset-parabolic design with careful attention paid to the mass and volume. The JPL developed receiver requires only minor changes to the current housing. The radiometer payload is expected to utilize 1.5 Us of the 3U CubeSat. The primary effort will be packaging the components into the available volume with careful consideration of the thermal environment for radiometric stability considerations.

3. CUBESAT BUS

The 1.5U JPL 183 GHz radiometer payload will be integrated with a 3U CubeSat developed at ARC. CHARM will utilize 4 deployable solar panels and will be spin-stabilized by means of an active attitude determination and control system to maintain the orbit rotation requirements. Communications will be performed using an L3 UHF Cadet radio with the ground segment at NASA Wallops. Integration and test activities will ensure that CHARM is compliant with the carrier requirements.

The system block diagram shown in Figure 3 depicts the interaction of CHARM's functional components. The bus is of high heritage based on the design of the NASA Ames Nanosatellites (Genesat-1, Pharmasat [5], Nanosail-D [6], O/OREOS [7]), with the frame constructed of Al 6061 and 7075, and designed such that the payload and bus are thermally isolated, with the latter's temperature controlled by passive means.

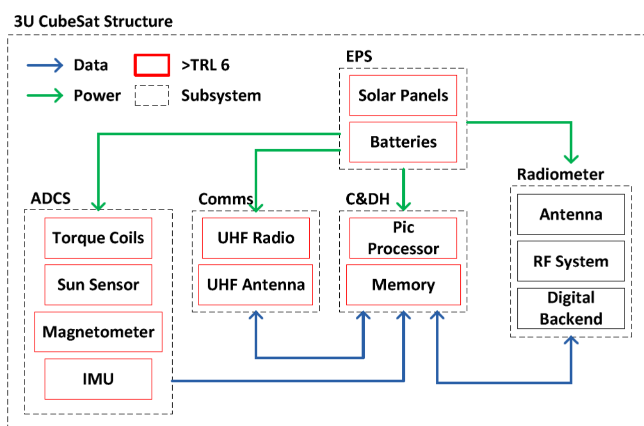

Figure 3. System block diagram. Majority of components are >TRL6.

Modifications include the addition of 4 deployable solar panels, replacement of the existing radio with the L3 UHF Cadet radio and addition of an active ADCS. Flight system technical margins are shown in Table 1, in which only the system mass and volume margins are under 30%. However, given the high TRL of the bus and its components, as well as ARC's experience in building nanosats, this is not expected to be an issue. The mass and volume margin allocated for the radiometer instrument is in excess of 30%.

Table 1. Flight system technical margins.

System Parameter	Mission Requirement	CHARM Design	Margin (%)	Notes
Payload Mass (kg)	2 w/ contingency	1.5 w/o contingency	33	>TRL4 Parts (>30% Required)
Bus Mass (kg)	3.52 w/ contingency	3.20 w/o contingency	10	High TRL Parts (>10% Required)
Launch Mass Margin (kg)	<6	5.5 incl. contingency	9	High TRL Bus (>5% Required)
Payload Volume Margin (cm^3)	<1500	1044	44	>40% for Packaging
System Volume (cm^3)	<3000	2500	20	High TRL Parts (Standard Sizes)
Energy Storage (Wh)	>10.3	16.3	58	Max Eclipse 38min
Max Battery DOD (%)	<40	25	60	470 Cycles Expected
OAP Harvest (W)	>10.3	13.8	34	For Spinning S/C
Data Downlink (MB/day)	>48	110.4	130	2 Links/Day Used >5 available

3. ASSEMBLY INTEGRATION AND TEST

The integration and test (I&T) plan, managed by and executed at ARC, is based on the successful methods implemented in the GeneSat, O/OREOs, and PharmaSat projects at ARC. CHARM flight systems are Class-D Prototype Payload Hardware per NASA NPR 8705.4, Risk Classification. Qualification testing is required to verify safety compliance and interface compatibility, and to meet the launch vehicle requirements. Acceptance tests are run for critical performance parameters for instrument and spacecraft systems. NASA-STD-7002A (Payload Test Requirements), was consulted to develop our existing plans, which will be adjusted to CHARM-unique requirements.

The I&T process leverages successful subsystem development and test procedures implemented by subsystem providers such as SCU, Pumpkin, L&M Electronics, and Micronics, making this largely an integration of "state of the industry" systems, with minimal development.

4. MISSION OPERATION

CHARM has been selected for launch by the NASA CubeSat Launch Initiative (CLI) with a tentative manifest around the October 2013 timeframe. Figure 4 depicts the mission operations concepts and summarizes key parameters. The nominal obit will be attainable by an International Space Station (ISS) resupply launch - a 51.6° angle of inclination at 325 km - however other orbits are also compatible. After deployment from the Poly-PicoSatellite Orbital Deployer (P-POD), CHARM will extend the solar panels and enter a high drag, quasi-stable configuration, with the ADCS aiding in the initial detumble.

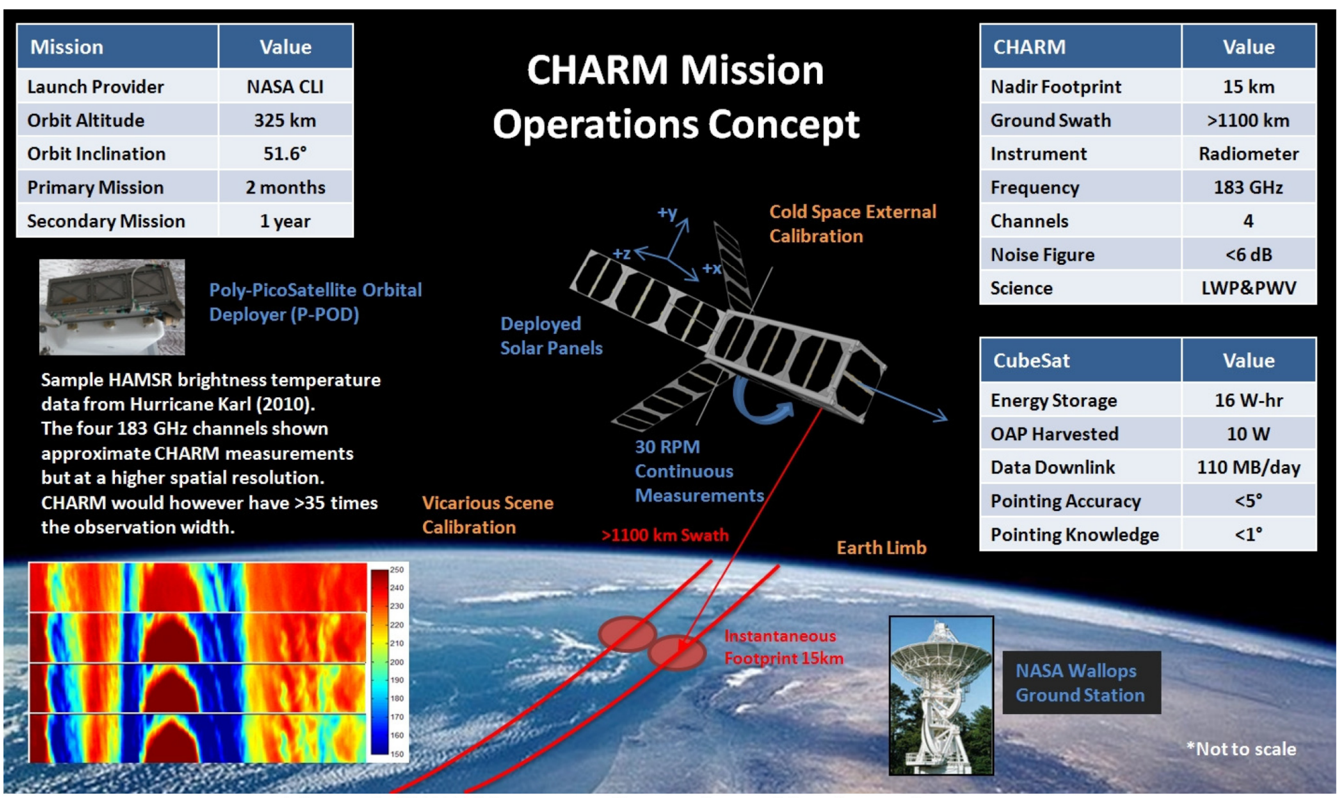

Figure 4. CHARM concept of operations with relevant instrument, CubeSat and mission parameters.

Once the communications link has been established, the payload will be activated and the spacecraft will then spin-up to the required rotation rate. The payload antenna, positioned on one of the long faces of the spacecraft, will then perform repeated cross-track measurements of the Earth, Earth limb, and cold space. A nominal spin rate of ~30 rpm is required for continuous on the ground measurements.

5. COMPARATIVE TECHNOLOGY ASSESSMENT

Current 183 GHz radiometer systems utilize mixer front-ends with typical noise figure of 9 dB. The CHARM receiver, utilizing the 35 nm InP MMICs, will at minimum reduce the noise figure level of the 183 GHz receiver to 6 dB. This represents an approximate improvement to the radiometer sensitivity or the noise-equivalent differential temperature (NEΔT) by a factor of 2. CHARM will be the first mission to fly the state-of-the-art InP MMIC low power and low mass 183 GHz low noise amplifiers.

Table 2. Summary of several CHARM spacecraft parameters with the 2 recent spaceborne instruments carrying 183 GHz channels

Instrument	CHARM	MHS	ATMS
Channels	4	5	22
Dimensions (cm x cm x cm)	10x10x30	75x70x64	70x40x60
Volume (cm^3)	3000	289800	168000
Mass (kg)	5.5	50	75
Power (W)	10	61	100

Table 2 compares the CHARM spacecraft to two different microwave radiometer instruments currently in use [8]. The Microwave Humidity Sounder (MHS) is a water vapor specific instrument; CHARM has 60% comparable functionality (3 of 5 shared channels) at 1% of the volume, 11% of the mass, and 16% of the power. The Advanced Technology Microwave Sounder (ATMS) is the most recent microwave radiometer instrument suite with a wider range of frequencies; CHARM has 18% comparable functionality (4 of 22 shared channels) at 2% of the volume, 7% of the mass, and 10% of the power. CHARM compares favorably in performance even when comparing the entire CHARM flight system to the respective microwave instruments

6. CONCLUSIONS

The design of a 183 GHz CubeSat water vapor radiometer for Earth Science is presented. CHARM would utilize state of the art microwave radiometer receiver technology with constantly improving CubeSat parts to perform measurements previously only possibly on physically larger satellites at a fraction of the cost.

7. ACKNOWLEDGEMENTS

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